PROGRESS IN AERONAUTICAL ENGINEERING

BY COMMANDER J. C. HUNSAKER, U. S. N.

THE first flight of an aeroplane, the first crossing of the English Channel, the first loop in the air, the first flight across the Mediterranean, the recent flight from England to India, and now the crossing of the Atlantic via the air are milestones, which mark the progress of the conquest of the air by man. At each stage in this progress, a daring navigator has always been ready to take the latest creation of the builder's art and to set out on a hazardous voyage. The first voyage is always hazardous, but with frequent repetition, it becomes commonplace enough.

It has fallen to the lot of the United States Navy to make the latest step in the progress of aerial navigation. The crossing of the Atlantic by Lieut. Commander A. C. Read and his crew in the Naval Flying Boat NC-4 marks the result of two years of engineering development and research stimulated by the War. Two years ago, the crossing was impossible, because the NC-4 could not have been built. The Liberty motor was not then in existence, the light and strong construction necessary for hull and wings was not understood, the special instruments and equipment had yet to be devised, and in short, aeronautical engineering as an art was not sufficiently advanced to design and construct this powerful type.

During this time, experience was being gained with smaller craft. For example, in 1915 our most powerful Naval seaplanes had 90 horsepower, in 1916 this was raised to 160 horsepower, in 1917 to 400, in 1918 to 800, and now in 1919 the NC type has 1600 horsepower divided among four engines. The size, endurance, safety and reliability have gone up almost in proportion. The displacement of the hull, which is a measure of seaworthiness, has increased from one ton to fourteen tons; the endurance in continuous

flight from two hours to over twenty; the passengers carried in the boat from two to over fifty. At the same time, the speed of small machines has been raised from 60 miles to 160 miles per hour.

These advances in the art are known to the public through the records broken, and have apparently come with astonishing rapidity. Compared with progress in other arts, aeronautical progress has been, indeed, stupendous, but to the aeronautical engineer each advance has come as the culmination of many short steps, each the result of patient and prayerful research and experiment and often saddened by a shocking accident.

It would not be safe, however, to extrapolate the curve of progress made in recent years, in an attempt to forecast future development. The stimulation of war will be removed, and neither funds nor lives will be risked so freely. Furthermore, in the beginning aeronautical engineering was new, and the sister arts, mechanical engineering and naval architecture, were well established. Much of our recent progress consists in the application in the air of materials, principles and processes already in use.

The NC flying boats were built to apply all that we had learned from previous experience, what we could deduce from theory, and what we could learn from foreign practice.

The principal advances in the art which made this boat possible are:—

(1) The Liberty engine which gave us a light, powerful and reliable power plant, economical of gasolene and oil and fit to run for long periods of time.

(2) The theory of wind tunnel experiments made on small models which enabled us to calculate the balance, stability and speed in advance of actual building.

(3) The application of the naval architect's towing tank or model basin to predict the seaworthy and hydroplaning quality of the hull.

(4) The application of the bridge designer's theory of structures to the design of the aeroplane wings.

(5) The definite knowledge of the mechanical properties of spruce as affected by density, moisture content, heat treatment, and natural defects which permitted us to use this wonderfully light and elastic wood with confidence; that is to say without allowing the usual factors of safety.

(6) Experience with laminated and hollow wood structural members.

(7) Experience with light hull construction in motorboats and other flying boats.

(8) The theory of balancing control surfaces, so that a man of ordinary strength could control the flying boat in the air as easily as a boat half the size.

(9) Alloy steels for metal parts of 150,000 lbs. tensile strength, which permitted important reduction in weight.

(10) Instruments to indicate speed and altitude in flight so that the pilots could fly at night without reference to the horizon or "feel" of the boat.

(11) Organized engineering which takes the place of invention and makes use of the special knowledge of many people.

(12) Assembly manufacture—that is; manufacture of parts at a great number of places by people expert in a specialty to be assembled into the complete structure.

The final design of the NC flying boat is recognized as an important advance in the art. It is, as would be expected, a distinctively American type since it makes use of American practices, standards, and materials, and is adapted for that peculiarly American institution, assembly manufacture.

With aircraft, as with battleships, destroyers and other men-of-war, the types used by the United States Navy have come to be known as distinctively American types, although the military problem solved by each type is usually not distinctively American. This result has to a large extent come about through a natural American prejudice against copying features of design and construction with which we are inexperienced. The prejudice is, of course, a stimulant to originality, but must be tempered by good judgment or good engineering, which is the same thing. A constructor, while he should very properly hesitate to copy practices he only half comprehends, must at the same time be quick to recognize the merits of a foreign development and to adapt or adopt its good features in his own work.

During the War, the Navy selected only one foreign type to be copied in the United States. This was the British Admiralty's flying boat F-5, plans of which were brought to the Naval Aircraft Factory early in 1918. Pro-

duction was shifted over to the new model at the expense of considerable trouble and delay because it had a superior bomb capacity and air endurance. But as soon as a start was made to prepare the necessary production data for the factory and its sub-contractors, it was realized that very material changes would have to be made. In fact, before the boat was finally got into production it resembled the British prototype only in externals.

The Navy, for aircraft as for ships, does the greater part of its own designing and building through its Corps of Naval Constructors. At the same time, private design and construction is encouraged by contracts with builders retaining engineering control in the Department.

The NC flying boats represent a typical example of how the Navy operates on the engineering side. Their design and construction made use of available talent, both in and out of the service, the facilities of parts makers, the new materials developed during the war, and, in general, represent the result of organized engineering rather than invention. For this reason, no one man can be said to have designed these craft, although the Chief Constructor of the Navy, Admiral Taylor, was at all times responsible for ways and means and results as well as the initial conception of the project.

The development of really large flying craft before 1917 was held back mainly because no suitable engine had been developed. Several attempts, both at home and abroad, had resulted in failure. When the 350 H. P. Rolls-Royce became available the four engine Handley-Page in England was brought out. But in the United States no American engine was in sight until about August, 1917 when the preliminary work on the Liberty began to look promising.

Admiral Taylor, as a member of the Aircraft Board, was in a position to weigh the evidence as it came in and to foresee the ultimate success of the new engine. This engine, then known as the "United States Motor" was still under a cloud of unfavorable comment from foreign and domestic experts, but the early troubles were recognized as natural and inevitable and the chance of success looked good.

About this time, the German submarines were extremely active and successful and there were grave doubts if there were shipping available to transport to Europe the great tonnage of American material necessary to prosecute

the war. In particular, one of the weapons needed to keep down the submarine was the flying boat, and unless we had a great number of flying boats on patrol over the European sub-infested seas, the shipping space available would be rapidly diminished, and unless there were shipping space the flying boats could not get over. It was a vicious circle, and could be broken only by flying the boats across the Atlantic under their own power.

For 1918, we had a large program of flying boats which were indeed large, but not quite large enough safely to be flown across the Atlantic. In 1919, we needed something bigger and to prepare for quantity production, the experimental models would have to be brought out in 1918.

The first step to provide the trans-Atlantic boats was the following memorandum:—

Washington, D. C.,
August 25, 1917.

From: D. W. Taylor, Chief Constructor, U. S. N.
To: J. C. Hunsaker, Naval Constructor, U. S. N.

The United States motor gives good promise of being a success, and if we can push ahead on the aeroplane end, it seems to me the submarine menace could be abated, even if not destroyed, from the air.

The ideal solution would be big flying boats or the equivalent, that would be able to keep the sea (not air) in any weather, and also able to fly across the Atlantic to avoid difficulties of delivery, etc.

Please think it over very carefully, particularly as to the method of procedure to develop something as close to the ideal as possible.

Design studies were at once put in hand and from time to time various men were called in consultation with the regular design staff of the Bureau of Construction and Repair.

Ideas and suggestions from all sources were considered, and the design itself became a composite of ideas, these ideas being chosen and incorporated into the design on the basis of suitability and merit and without reference to source.

Plans were then prepared for a boat of this character to be fitted with three engines and for one to be fitted with five engines. The predicted performance was computed for each boat from which it appeared that the three engine boat could be made to satisfy the general requirements of the problem and could be much more quickly built and with smaller risk of failure. Investigations were undertaken to determine in a preliminary way the construction

of wing beams, struts, and the principal structural members, the proportions of wing area, fin and control surface areas, and the materials to be employed for important parts. The general appearance of the design was worked out and the procedure established to be followed in making the detail drawings.

A three-foot model of the design was then tested in the wind tunnel of the Washington Navy Yard and the size and arrangement of tail surfaces needed to guarantee stability and correct balance in flight determined. With a machine of the unprecedented size contemplated, it was vitally necessary that there should be no doubt on this score as an accident on the trial flights would set the project back many months besides risking the lives of the crew.

Similarly, a series of models of the hull was made and run in the towing basin. These tests enabled a prediction to be made as to the hydroplaning and seaworthy qualities of the full size boat. The lines of the best of this series were chosen for the final design, and I am very happy to say, on trial fully justified our confidence in the tank study. It is believed that this hull form is superior to anything that has been produced to date. A radical step was taken in departing from the conventional practice of providing a wide bottom to give early planing at moderate speeds over the water in favor of a narrow hull of easy lines and strong Vee bottom which would get its planing by speed rather than by lift. The form of the boat was such that this speed could be reached quickly. Previous practice had been to provide one inch of beam for every 100 lbs. of weight carried. The NC hull planes easily at 230 lbs. per inch width. To obtain this, a speed of 65 miles per hour over the surface of the water is necessary, as against 55 miles with our former constructions. However, the steep Vee bottom and easy form permit this speed, even in a choppy sea. The seaworthy quality of the hull was well proved by the NC-3 which rode out a gale off the Azores for over two days.

The design being worked upon was of dimensions so far beyond any previous experience in this country that much unfamiliar territory had to be covered. In order that the design might be successful, new methods of construction were required as, otherwise, the weight of the design would increase with such rapidity as to make success impracticable. In the state of design information and knowledge, as

it existed in the United States on that date, this necessity was one of the greatest seriousness, and one which imposed upon the personnel connected with the design a great amount of investigation and experiment in the working out of the details referred to.

It soon became apparent that the carrying on to the completion of design work of such dimensions at the Bureau in Washington would be impracticable, unless our entire facilities were devoted to this work. Under the enormous pressure of air matters connected with the war, this was wholly impracticable, and it was decided to arrange with the Curtiss Aeroplane and Motor Corporation of Buffalo, N. Y., to complete the drawings with their own design facilities, and with the contribution by themselves of such ideas of value as might develop under the control and supervision of the Bureau.

A contract was, therefore, made with the Curtiss Company for the performance of this, the drafting and design work. Under the terms of this contract, they were to carry out all work directed by the Navy Department, furnishing in connection therewith all facilities necessary. The Bureau of Construction and Repair reserved to itself the direction and oversight of all work coming under that Bureau and, for this purpose, placed in charge, as its Field Representative, Naval Constructor G. C. Westervelt, U. S. N. Active work on the detail design was begun in Buffalo early in October. Shortly after the commencement, Naval Constructor H. C. Richardson, U. S. N., was ordered for duty in connection with the design of the boat hull.

In carrying on the actual work of design, the design as a whole was first divided into its main elements. These main elements were designed or approved by the Bureau of Construction and Repair. The details of these main elements were then distributed to the members of the design force at Buffalo working upon them. All ideas, whether of the Curtiss Company or of the Navy, were pooled, and as details were worked out the decision as to the solution to accept was made as a result of discussion.

At this time, the boats were designated NC, the N for Navy and C for Curtiss, indicating joint production. Four units were built, NC-1, NC-2, NC-3 and NC-4. NC-1 was completed and flown October 4, 1918, or approximately one year from the commencement of the design. The trials

were a source of great satisfaction as it was demonstrated that the control and balance in the air were very satisfactory, and in accordance with the prediction of the wind tunnel tests, and that the performance on the water was all that could be desired and entirely justified the confidence placed in the model tests in the towing basin. No structural weakness developed and the speed came out as predicted. In short this flying boat designed from theoretical and model experimental data, combined with the practical experience of a half dozen or more people, performed in every way so close to her designed characteristics as completely to justify the methods of the naval architect as here applied in the design of a flying machine.

As flying tests on the first boat were continued, many changes were tried to improve the original design, and as these were found advantageous, were incorporated on this and on the other three boats building.

The month of November, 1918, was spent in thoroughly trying out the NC-1. Among other flights a round trip from Rockaway, N. Y., to Washington, D. C., via the entrance to Chesapeake Bay, was made with nine people on board. On November 25 the NC-1 broke the world's record for passenger carrying, having on board in the air 51 persons. One of these was a stowaway, who had concealed himself in the interior of the hull for over an hour prior to the start of the flight, and is probably the first man to deliberately stow himself away on an airplane in order to make a voyage. On these flights Naval Constructor Richardson was in charge and was one of the pilots.

After making various minor improvements, it was concluded that the maximum which could be obtained from three Liberty engines had been reached and no further improvements in performance could be expected until geared Liberty engines became available. The geared engines were still in an experimental stage. It was apparent, however, that the flying part of the craft could sustain a greater load if more power were available, and it was accordingly decided to add a fourth engine, making a total of four Liberty engines. The second boat completed, designated as NC-2, was, therefore, fitted with four Liberty engines arranged as two pairs of tandems, on its trials in March, 1919, successfully flew with a total weight of 28,000 lbs. The addition of the fourth engine, which increased the

dead weight of the boat by about 1,500 lbs., permitted about 3,300 lbs. of extra weight to be carried, or a net gain of 1,800 lbs.

The NC-3 and NC-4 were completed in April, 1919, and were likewise fitted with four high compression Liberty engines, but with a somewhat different arrangement. In these two boats two engines were arranged on the center line as a tandem pair with the other two engines mounted on the wings as tractors, as were the wing engines on the NC-1. In these boats a further change was made by omitting the center nacelle and placing the pilots in a cockpit in the hull. This arrangement of engines is novel and has the advantage of concentrating weights near the center of the boat so that it can be maneuvered more easily in the air.

Due to injury to two outer wing sections while at anchor in a gale late in March the NC-1 was put temporarily out of commission. After the completion of weight-lifting trials on the NC-2, the outer wing sections of that boat were transferred to the NC-1 as no spare wings were available. Except for this regrettable injury, all four of these boats would have been able to leave Rockaway Beach together for the trans-Atlantic Flight.

The hull of the boat is 45 feet long by 10 feet beam and is divided into six watertight compartments, which are used for the following purposes: No. 1, Navigator's cockpit, with compass and navigating instruments, charts, etc.; No. 2., Pilot's cockpit with seats and controls for the principal pilot and his assistant, reserve compass, air speed meter, inclinometer, turn indicator, barograph, engine throttles and self-starters; No. 3., Hold, for crew off watch to rest, spare parts, provisions, etc.; Nos. 4 and 5, Tank compartments with gasolene tanks, gages, engine instruments and mechanician's station; No. 6., Radio station with radio operator, sending and receiving sets, radio telephone and direction finder. There is provision for pumping out the bilges and for ventilation to blow out gasolene fumes. A windmill pumps gasolene from the main tanks to a gravity tank in the top wing. Another windmill generates current for the radio and starter battery.

The control surfaces are all carefully balanced so that the pilot needs his assistant only in bumpy air. Indeed, in still air the craft is so inherently stable that the pilot has nothing to do but keep his course.

The wings are remarkable chiefly for their size and lightness. The span is 126 ft. and area 2,380 sq. ft. The load carried in flight is 11.7 lbs. per sq. ft., yet the wings only weigh 1.2 lbs. per sq. ft.

The maximum cruising range is calculated at 1400 nautical miles. This cruising range depends of course on normal functioning of the engines and the absence of head winds. The flight to the Azores of about 1250 nautical miles indicates that the calculated range is not unduly optimistic. The boats were originally planned to fly across the Atlantic and then to hunt submarines. The trans-Atlantic part has now been successfully accomplished and it is hoped that there will be no more need for submarine hunting.

The crossing of the Atlantic by a direct flight from Newfoundland to Ireland, especially with a land machine stripped for the event has already been proved possible. In that case greater endurance is obtained by sacrificing seaworthiness in case of a forced landing. The NC type, being designed for war service, has made no sacrifice in this regard. It is certain that larger flying boats than the NC will be built to have greater endurance and sea-keeping qualities. This will be the next step, and can be taken as soon as an important improvement in engines is made. There is small advantage now to be gained from merely adding more Liberty engines. The weight goes up as fast as the power and the endurance remains about the same. But it seems clear that improvements in engines will come, as they always have when needed, and we shall expect to see this improvement marked by the smashing of another record.

J. C. HUNSAKER.